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Autor: Reddi, S.A.

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Quality Concrete Production for Ganga Bridge, Patna, India

Réalisation de béton de qualité pour le pont sur le Gange à Patna, Inde

Herstellung von Qualitäts-Beton für die Ganges-Brücke in Patna, Indien

S.A. REDDI
Chief Engineer-Projects
Gammon India Limited
Bombay, India

S.A. Reddi, born in 1933, is a Fellow of Institution of Engineers (India). During the last 30 years, he was involved in the construction of more than 50 major prestressed concrete bridges. He is actively involved in the preparation of Standards for the Indian Standards Institution, Indian Roads Congress, etc. He has been a member of FIP-Working Group on Hot Weather Concrete.

SUMMARY

The various measures adopted for cost effective production of concrete and for ensuring quality during the construction of a 5,6 km long prestressed concrete bridge across the River Ganges at Patna, India are described. The quality control measures are devised in the context of the use of minimum equipment and labour intensive production practices in India. The results of statistical analysis of about 100000 concrete cube specimens are presented.

RÉSUMÉ

L'article décrit les nombreuses mesures prises pour la production avantageuse de béton et pour l'assurance d'une qualité correspondante pendant la construction d'un pont en béton précontraint, de 5,6 km de longueur, sur le Gange à Patna, Inde. Les mesures d'assurance de la qualité sont adaptées aux conditions de production en Inde, utilisant le minimum d'équipements et le maximum de travailleurs. Les résultats d'une étude statistique d'environ 100000 éprouvettes cubiques en béton sont présentés.

ZUSAMMENFASSUNG

Die vielfältigen Massnahmen zur kostengünstigen Beton-Herstellung für die 5,6 km lange Spannbeton-Brücke über den Ganges in Patna, Indien sowie für die zugehörige Qualitätssicherung werden beschrieben. Die Massnahmen zur Qualitätssicherung sind auf die investitionsarmen und arbeitsintensiven indischen Produktionsverhältnisse zugeschnitten. Die Ergebnisse aus der statistischen Prüfung von etwa 100000 Betonwürfeln werden mitgeteilt.

1. INTRODUCTION

A 5.575 km long bridge has been constructed across the River Ganges near Patna in Northern India. The foundations consist of 12m dia. concrete caissons sunk to a depth of about 55m below low water level. The cellular piers are in reinforced concrete. The superstructure consists of 121m single cell box girder spans, constructed using precast segments for the major portion of the bridge while the transition spans between land and water were cast insitu. (Fig. 1) About 300,000 cum. concrete of grades varying from 16 MPa to 45 MPa was used for the construction. The first stage of construction including the foundations and the substructure upto high flood level for four lanes of traffic and the balance substructure and the deck for two lanes of traffic was completed and the bridge opened to traffic in 1982. (Fig. 2). The second stage of the bridge construction was taken as a separate contract during the latter part of 1983 and is scheduled for completion in 1986.

2. SPECIFICATIONS FOR CONCRETE

The work is carried out as per Indian Roads Congress Specifications IRC:18 and IRC:21 for prestressed and reinforced concrete respectively. The Indian Standard Code of Practice for plain and reinforced concrete (IS:456) is also used. The concrete is accepted if the average strength of the group of cubes cast for each day is not less than the specified characteristic strength. 20% of the cubes cast for each day may have a value less than the specified strength provided the lowest value is not less than 85% of the specified strength. In terms of IS:456, the acceptance criteria is based on statistical analysis using standard deviation. Considering the large quantity of concrete involved, it was decided to monitor the quality using statistical concepts and at the same time satisfying the IRC Codes regarding standard of acceptance.

3. GRADES OF CONCRETE

The following grades of concrete were used :-

Caissons	16 and 20 MPa	A/c: 6.8	W/c: 0.55
Piers	25 MPa	6.3	0.50
	35 MPa	5.6	0.42
Deck	45 MPa	4.0	0.34

4. MATERIALS FOR CONCRETE

4.1 Cement

Indian cement conforming to IS:269 is used. In view of the considerable variation in the quality of cement produced by different factories (22-50 MPa @ 7 days), the source is carefully chosen after preliminary trials and the supplies are ensured from two factories only.

4.2 Aggregates

Coarse aggregates for reinforced concrete consist of natural river gravel obtained from a distance of about 300 km. Crushed broken stone was used for prestressed concrete, in terms of the contract requirements, even though tests with natural gravel indicated equal acceptability. Fine aggregates consisted of natural river sand. The use of natural gravel of 40mm maximum size

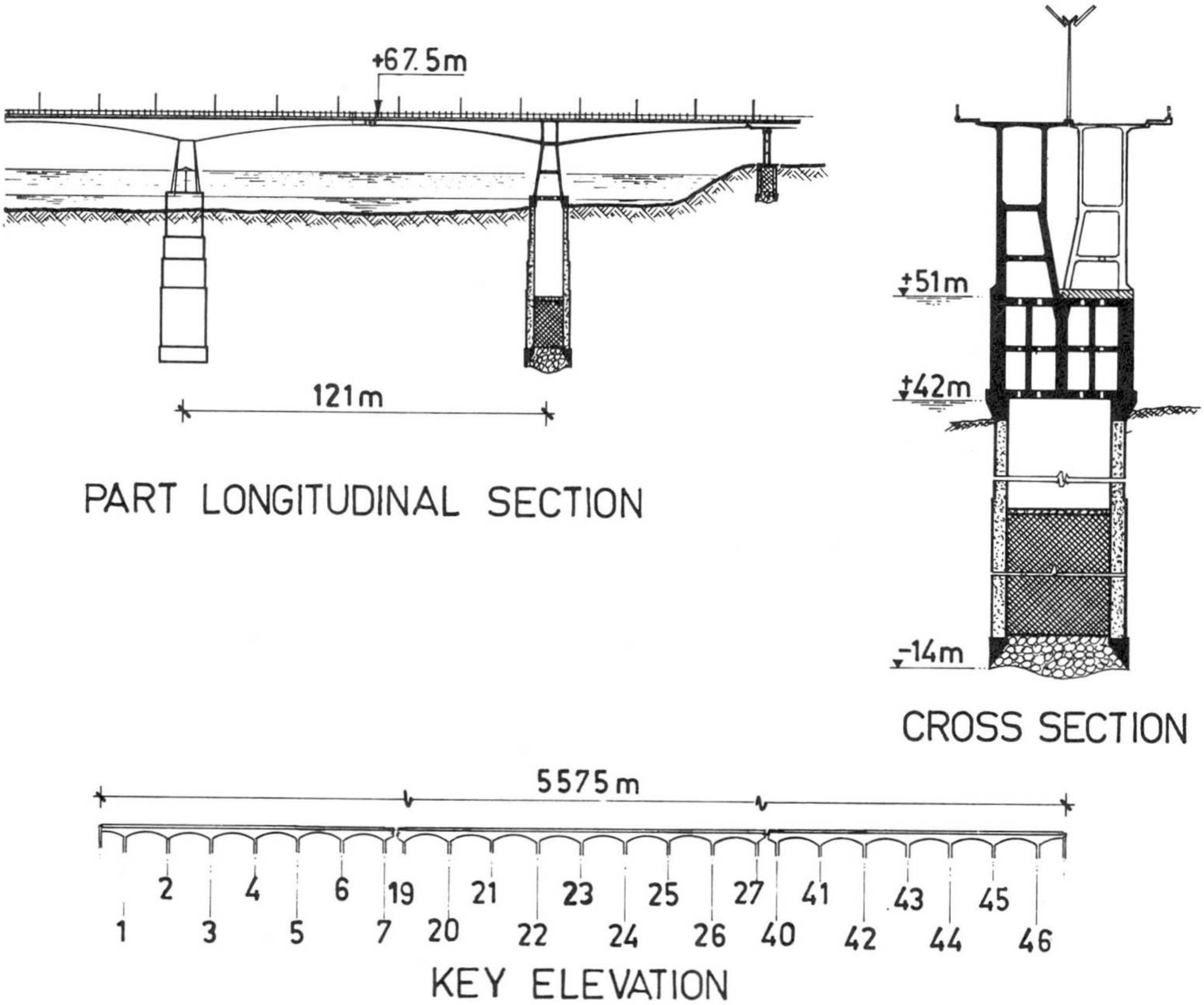

Fig. 1 Ganga Bridge at Patna - Details

Fig. 2 A View of the Completed Bridge (First Two Lanes)

particularly for Grade 35 concrete has resulted in substantial saving in cement (about 15%), partly due to the use of 40mm size and partly due to the use of rounded natural gravel. In order to facilitate use of 40mm maximum size in the reinforced concrete piers, the detailing of the reinforcement was suitably modified.

4.2.1 Grading of aggregates

The Indian Standard Code (IS:383) specifies the permissible range of gradings both for coarse and fine aggregates. While the individual gradings for coarse/

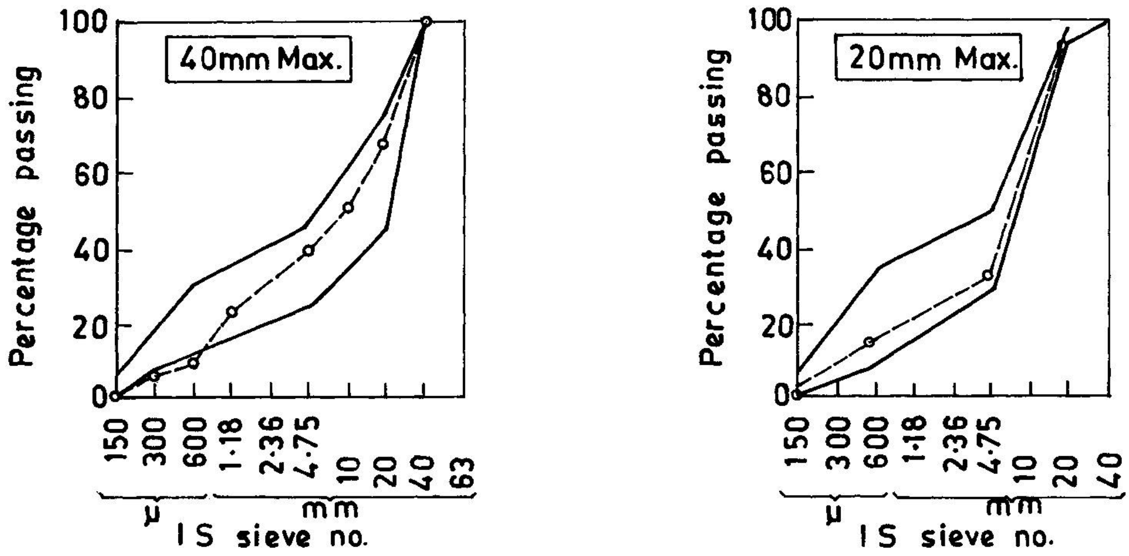

Fig. 3 Typical Combined Aggregate Grading

fine aggregates procured for the work were controlled only within a very broad spectrum, the grading of the combined aggregates was closely controlled. Sieve analysis of coarse and fine aggregates were conducted once a day and the nominal proportion adjusted to ensure the combined grading. (Fig. 3). The river gravel has a reasonably good natural grading and as such the material was used without further processing. The crushed stone of size 5mm to 20mm was obtained in one grade without separating the fractions below 10mm as is customary elsewhere. If the sieve analysis indicates deficiency or excess of fraction below 10mm, the grading is corrected by adding either 10mm or 20mm single size crushed stone, small quantity of which was kept at site as a standby. The sand was coarse (fineness modulus 2.5 to 3) and used without any processing.

4.3 Water

The river water obtained from the bridge site was used.

5. CONCRETE PRODUCTION

In view of the socio-economic compulsions prevailing in the country, minimum of equipment was used. Ordinary tilting drum type mixers (200 ltrs. capacity) were used for mixing concrete. The weight of aggregates was converted into volume to be measured using calibrated boxes. The contents of the boxes were checked for the weights daily prior to commencement of concrete and the height of the box adjusted if required. Water was fed into the mixer manually using 5 litre cans duly calibrated. The cement is received from the factory in 50 kg. jute bags and as such some loss in transit is expected. The cement bags are reweighed at site on a platform scale prior to use and any deficiency made good. The transportation of concrete is by manual labour. One tonne capacity hoists were used for vertical transportation for greater heights. Both internal and shutter vibrators were used for compaction.

6. MIX DESIGN

The target mean strength was arrived at based on the specification requirements and the standard of control expected to be realised by the construction agency. Very low workability was aimed at, in view of manual handling of the concrete. Apart from the 28 days strength requirements, high early strength (about 30 MPa at 72 hours) was also aimed at in order to ensure early prestressing. The strength-water cement ratio relationship was arrived at for a range of strengths based on trials at the field laboratory using the same cement and aggregates intended for the work. The choice of A/c ratio and W/c ratio are based on field laboratory tests.

6.1 Target mean strength

i) In terms of IS Code (IS:456), a margin of 1.64 times the standard deviation is added to the characteristic strength.

ii) In terms of IRC Codes, the lowest value should not be less than 85% of the specified strength. In practical terms, the margin required is three times the standard deviation to be added to 85% of the specified strength.

iii) The IRC Codes also specify the target mean strength as 1.33 times the characteristic strength for grades upto 35 MPa and a slightly lower value for higher grades.

The target mean strengths for grades 35 and 45 based on the alternatives are given below : (Values in MPa)

Characteristic strength	Standard deviation	Target Mean Strength(Alternatives)		
		(i) ISI	(ii) IRC	(iii) IRC
35	4	42	42	47
45	5	53	53	58

The assumed standard deviations are based on previous experience of the construction agency on similar type of work. The construction agency chose to follow Alternative (ii), resulting in substantial economies while satisfying contractual requirements.

6.1.1 Cement consumption

The cement consumption for grade 20 was governed by minimum requirements for durability. For grade 45, high early strength requirement at three days governed the mix design. Typical cement consumption for different grades are -

20 MPa	:	310 kg per m^3	35 MPa	:	340 kg per m^3
25 MPa	:	320 kg per m^3	45 MPa	:	450 kg per m^3

6.1.2 90 days tests

The cube strength at 90 days was also monitored regularly with a view to eliminate any testing errors and also to utilise the 90 days strength for checking the technical requirements, in case of an odd 28 days low strength. None of the members of the bridge are expected to be subjected to full load before 90 days. However during actual execution there was no need to tap this reserve.

6.1.3 Standard deviations

Cumulative standard deviations were being worked out regularly for each grade of concrete as well as for each component of the structure. The cumulative standard deviations for all the grades of concrete were within the limits assumed in the preliminary mix design. However, the standard deviations for the components fluctuated substantially. For 45 MPa concrete, the standard deviation of components varied from 3 to 6 and the corresponding values for 35 MPa concrete ranged between 2 and 5 MPa. Even where the individual component standard deviations exceeded the values assumed in the mix design, all the individual cube strength results satisfied the contractual requirements, presumably because of the higher mean strengths.

7. QUALITY CONTROL

Two levels of quality control were operated -

a) The contractor's internal control

A separate quality control cell and a field concrete testing laboratory with a 300 tonne cube testing machine, with test sieves and cement testing facilities were established by the contractor at the project site. Here all the preliminary trials and major portion of works tests are carried out.

b) The owner's control

After selection of the mix by the contractor, the trials are repeated in the owner's laboratory before mix was approved. Spot checks on works tests are also carried out in the owner's laboratory, besides witnessing all the tests in the contractor's laboratory.

7.1 Tests on aggregate

Sieve analysis tests were initially conducted at the quarries in order to choose the right type of aggregates. Subsequently, random checks were made at the quarry in order to avoid infructuous expenditure in transporting substandard material over a distance of 300 km. The routine monitoring of grading of fine aggregate at the source was confined to checking out material passing through 600 micron sieve, as this factor was considered critical. On testing, the aggregate crushing value was obtained at 18% and the aggregate value at 22%. The corresponding upper limits permitted by the courts were 30% for concrete in wearing surfaces and 45% for all other cases. Tests for the grading and moisture content of aggregates were conducted daily.

7.2 Tests on cement

Tests for compressive strength of cement at 3 days and 7 days were conducted at the field laboratory at frequent intervals, and on receipt of each consignment from the factory, in addition to the manufacturer's test certificates, to determine the suitability of cement and also to monitor the deterioration during storage, particularly during the rainy season.

7.3 Workability of concrete

Slump and compaction factor tests were conducted daily. While the values of slump range from 0 to 10mm, the compaction factor is in the range of 0.7 to 0.8.

7.4 Works tests

The works test samples were taken daily and tested. The pressure gauges were calibrated by an independent testing laboratory once in a year. Master gauges were maintained at the site laboratory for more frequent checks, usually at monthly intervals.

8. ANALYSIS OF TEST RESULTS

Nearly 100,000 cube specimens have been tested for preliminary trials, strength at transfer of prestress, 7, 28 and 90 days strengths removal of formwork, etc. A number of tests on accelerated-cured concrete specimens as per IS:9013 were conducted. Tests were also conducted to obtain correlation between cube strengths and rebound values of Schmidt hammer which was used on two occasions to confirm the quality of the concrete where the cube test results were marginally lower.

9. HOT WEATHER CONCRETING

During summer months, with day temperatures reading 43°C, the concreting operations were restricted to either early morning or late evening. Survey of

Period		Nov. - Jan.		Feb. - Mar.		Apr. - Jun.	
Climatic conditions	Relative Humidity %	52-71		27-62		24-71	
		Max.	Min.	Max.	Min.	Max.	Min.
	Temp. °C	32	7	38	9	43	19
Concrete Grade (MPa)		45	35	45	35	45	35
28 days average strength (MPa)		57	49	56	49	59	51
7 days average strength (MPa)		43	38	45	39	48	44
% of 28 days strength		76	79	79	80	81	85
90 days average strength (MPa)		61	53	69	54	64	57
% of 28 days strength		107	110	122	110	108	111

Table 1: Analysis of strength of concrete placed under varying climatic conditions.

available literature indicated possible reduction of 28 day strength under hot weather conditions. However both the trial mix results and the works test results (Table 1) do not indicate any reduction in 28 day strengths for concrete carried out during hot weather conditions, upto an ambient temperature of 43°C in the present case.

10. AGE-STRENGTH RELATIONSHIP

An analysis of a large number of test samples indicates the 7 days strength at 75 to 80% of the 28 days strength, particularly for higher grades of concrete, and the works test results at 7 days were evaluated accordingly. The 90 days strength have been found to be about 110% of the 28 days strength.

In terms of the ISI/IRC Codes, the 7 day and 90 day strengths are indicated as 66% and 110% respectively, of the 28 day strength. However, in view of the actual test ratios indicated above, the works cube test results at 7 days were evaluated, to ensure that these are not less than 80% of the characteristic strength.

11. MODIFICATIONS TO CONCRETE MIX

Based on the cumulative standard deviation for various grades of concrete, minor modifications in the mix proportions were effected from time to time, to ensure the design assumptions regarding target mean strengths. The maximum variation in A/c ratio was 0.2 and the W/c ratio for 45 MPa concrete fluctuated between 0.34 and 0.36. Though the grading of combined aggregate varied substantially from time to time within the upper and lower bound limits specified by the IS Code, such variations were not found to affect the strength of concrete at all. However, the workability was affected to some extent.

It may be noted that the mix proportions have been arrived at, based on the field laboratory trials and as such do not exactly fit into the pattern envisaged by various published methods. The percentage of fine aggregates used in the context of coarseness of sand is substantially lower than those recommended by the ACI or the British (Transport & Road Research Lab) method of mix design.

12. CONCLUSION

A level of technology appropriate to the socio-economic conditions prevailing in a developing country has been successfully evolved and realised in practice. The conception, design, engineering and construction of the bridge has been carried out indigenously out of internal resources, even though the contract was secured based on global tenders. Innovative methods of quality control as well as concrete construction which does not exactly fit into the traditionally accepted practices, have been successfully tried and implemented. A large amount of data collected from the various tests conducted in the field laboratory has helped in further rationalising the quality control methods for subsequent projects in the country.

CREDITS

Owners : Government of Bihar State, represented by its Public Works Department.

Designers & Contractors : Gammon India Limited, Bombay, India.